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Stark shift of individual quantum dots

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Abstract. We have studied the influence of electric field on the emission properties of individual quantum dots of InP, inbetween barriers of GaInP. The emission shifts with applied electric field, due to the quantum confined Stark effect. We find that higher energy lines quench at high field. In addition a change in the linewidth of the emission is found for high electric fields.

Introduction

Optical investigations of semiconductor quantum dots has recently become an active area of research. In particular, the investigation of individual quantum dots has determined that the linewidth of the emission is very narrow in a variety of systems [1, 2]. Spectroscopy under different perturbations such as electric field [3] and magnetic field [4] for InAs quantum dots coherently embedded in GaAs have been performed. We will here describe the results of the influence of electric field on InP quantum dots embedded in GaInP, lattice matched to GaAs.

Experimental details

The sample we used was grown by metal-organic vapour phase epitaxy, and contained InP quantum dots in GaInP, lattice matched to GaAs (n-type). The dots are shaped like truncated pyramids, and have a typical height of 15 nm [6] Gold was evaporated on the surface to form a transparent Schottky contact. The emission was excited by a frequency-doubled YAG-laser emitting at 532 nm. A typical measurement temperature was 5 K. Since this was a low density sample, a microscope was used to separate the emission spectra from individual dots. The emission was excited by a frequency-doubled YAG-laser emitting at 532 nm. A typical measurement temperature was 5 K. An applied bias of 1 V corresponds to an open-circuit situation under illumination.

Results

Figure 1 shows emission spectra of one InP quantum dot as a function of applied bias. The peaks shift to higher energy with increasing electric field (which corresponds to decreasing applied bias). This is opposite to the conventional Stark shift in e.g. atoms which decrease the transition energies with increasing field. The quantum dots are however not symmetric in the z-direction (the growth direction) and there is thus no symmetry argument for a conventional sign of the Stark shift. At zero electric field, calculations show that the electron wavefunction is localised centrally in the quantum dots, whereas the hole wavefunction is localised mainly at the bottom of the pyramid [5]. For increasing electric field (pointing out of the substrate) the hole wavefunction will be localised more centrally in the pyramid, experiencing a higher potential. Another observation is that the higher energy peaks quench with increasing field. Similar behaviour has been observed for defects and was attributed to field assisted tunneling which is more effective for higher energy states. Although we

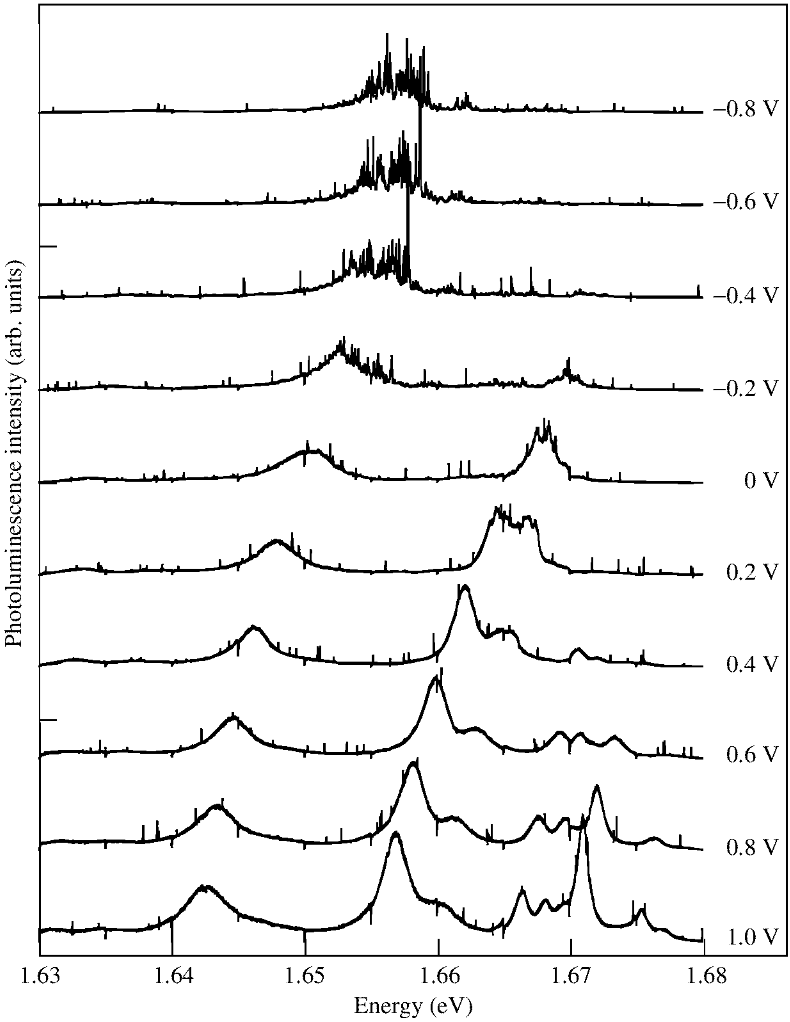

Fig. 1. Photoluminescence spectra of an InP quantum dot as a function of applied bias. The emission consists of several lines which show a Stark shift.

do not know the origin of the multiple lines, this observation supports an electronic origin. At the highest field, we observe that the originally quite broad lines split into sharp lines. We have calculated the carrier concentration in the sample as a function of electric field and illumination. We find that the carrier concentration decreases rapidly with increasing electric field, in particular for electrons. We attribute the broadening at zero electric field to interactions between carriers in the quantum dot and carriers in the wetting layer or the barrier. Similar phenomena have previously been observed in the InAs system [ ].

We have calculated the transition energies as a function of the electric field. The model is an 8-band k.p model in conjunction with the envelope function approximation and includes a realistic shape of the dots, strain and piezoelectric polarisation. For electric fields however, we have introduced infinite barriers, in order to get bound states instead of resonances. In order to obtain the electric field, we solved the Poisson equation using a

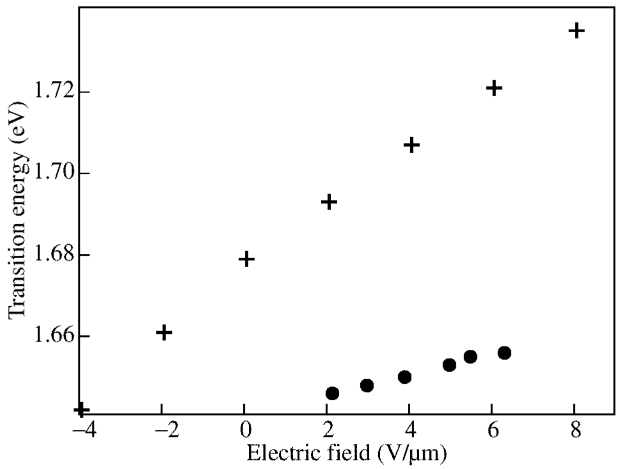

Fig. 2. Calculated (crosses) and measured (filled circles) transition energies as a function of electric field.

drift-diffusion model which also takes into account the photo-generated carriers. Figure 2 shows a comparison of the calculated and the experimental transition energies. We consider the agreement to be good and we attribute the remaining differences primarily to the difficulty of modelling the field correctly as well as to the use of infinite barriers in the calculation.

Acknowledgements

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